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# Hydrology of Black Mesa Watersheds, Western Colorado

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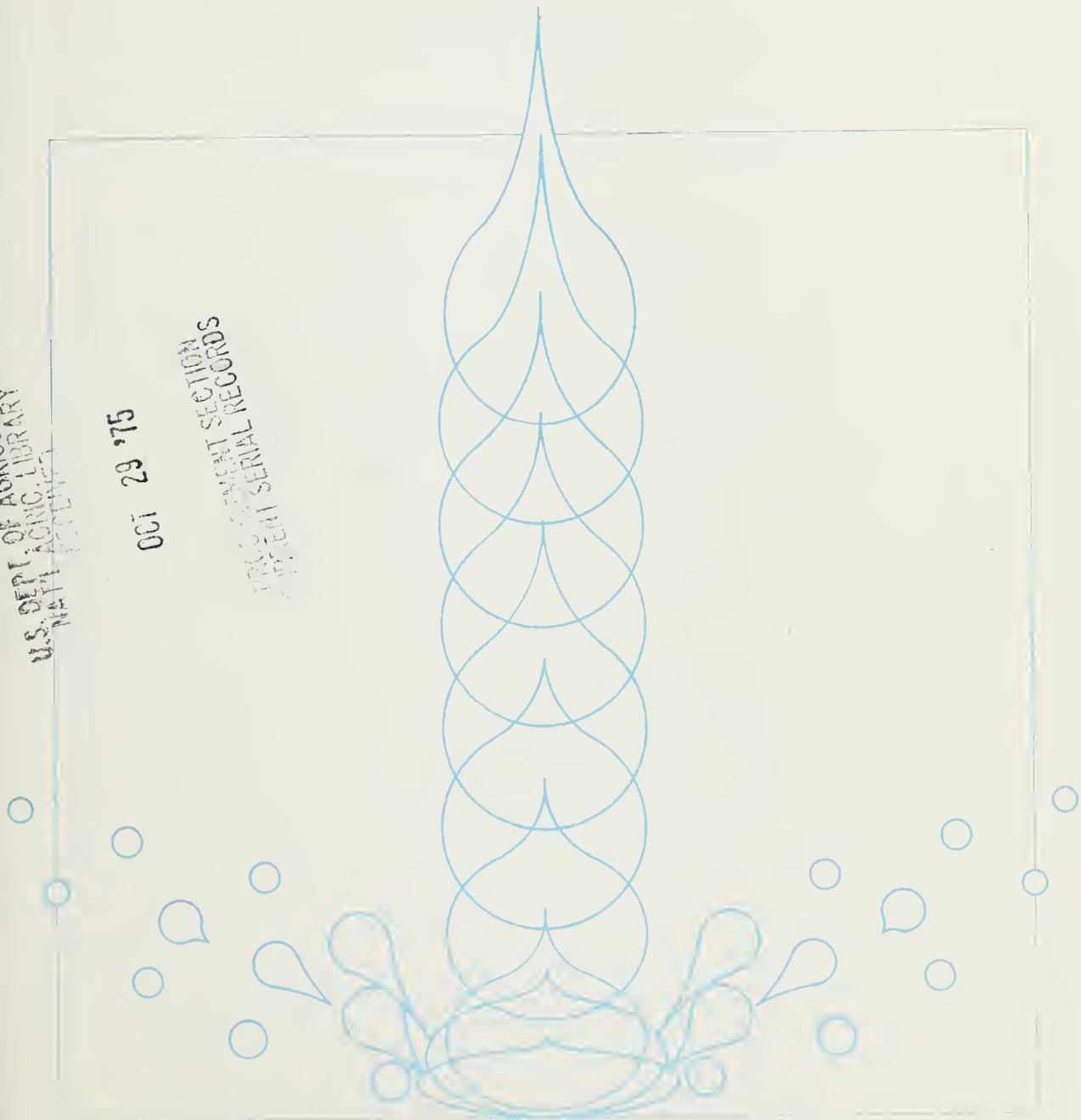
USDA Forest Service
General Technical Report RM-13

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

June 1975



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## Abstract

Frank Ernst C Harry F Brown, and J R. Thompson
1975. Hydrology of Black Mesa watersheds western Colorado USDA For. Serv. Gen Tech Rep. RM-13, 11 p. Rocky Mt. For and Range Exp Stn., Fort Collins, Colo. 80521.

In 1956 three experimental watersheds were instrumented on Black Mesa in western Colorado. The hydrology of these mesa lands previously had been almost entirely ignored Of primary concern was the determination of sediment-ground cover relationships on these important livestock grazing areas.

Eleven years of runoff and suspended sediment data show no relationship to bare soil intercept This lack of relationship is probably due to the experimental error in measuring these small amounts of sediment. Bare intercept decreased on each watershed during the 1957-67 period even though grazing utilized an average of 40 percent of the grass in the open parks on one of the watersheds.

While suspended-sediment concentration after summer storms can be as much as six times that sampled during snowmelt total yield averages 91 lb acre from spring runoff and 11 lb acre from storm runoff because of the small volume of flow Based on current erosion classification schemes, these are very minor amounts of "geologic erosion."


**Keywords:** Hydrology, runoff, suspended sediment, Black Mesa watershed..

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USDA Forest Service
General Technical Report RM-13

June 1975

# Hydrology of Black Mesa Watersheds, Western Colorado

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# Hydrology of Black Mesa Watersheds, Western Colorado

Runoff and sediment production are important considerations in multiple use management of mountain rangelands. The problem is to find ways to predict these factors from easily measured values.

The wasteland look of heavily grazed ranges from earlier eras focused attention on the role of plant cover. The results of numerous infiltrometer studies have been used to quantify the relation between the amount of vegetative cover and runoff and sediment. For example, Turner and Dortignac (1954) evaluated infiltrometer measurements on several mountain grassland types in western Colorado. They concluded that dense Thurber fescue sites averaging 6 percent bare soil provided maximum protection for the soil, while poor weed types with 58 percent bare soil did not furnish adequate watershed protection. Packer (1951) recommended ground-cover densities (plant basal area plus litter) of 70 percent as one watershed protection criterion for bluebunch wheatgrass and cheatgrass ranges.

Evidence from mountain range watersheds, though relatively scarce, shows soil erosion and storm runoff increase rapidly as plant cover and litter diminish. One study in Utah sets the threshold level for this increase at exposure of more than one-third of the soil surface (USDA-FS 1948). Thus ground cover—or its near complement, bare-soil intercept—has become a basic part of the watershed protection criteria evaluated by managers of mountain rangeland. For rangelands at high elevations, little attention has been paid to the role of melting snow in causing erosion, possibly because land managers were impressed by the role of intense summer storms, or because they had little occasion to visit the mountain ranges in the spring.

For 11 years, starting in 1957, precipitation, streamflow, and sediment were measured from three small watersheds on Black Mesa (fig. 1) in the mountain grasslands of western Colorado to obtain information about hydrologic processes. Ground-cover

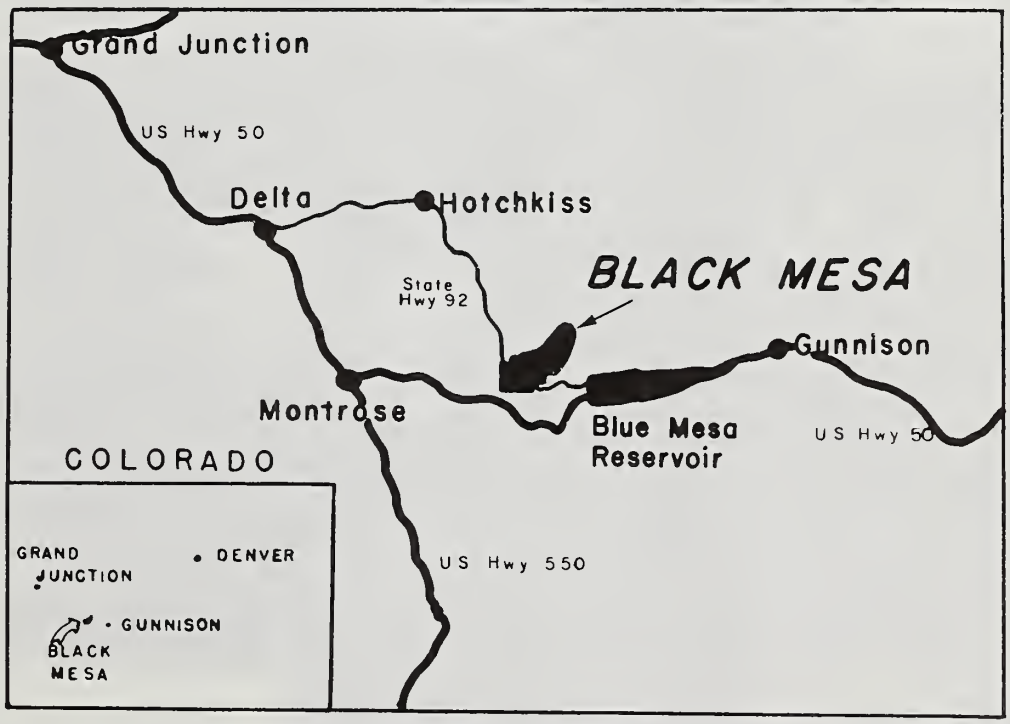


Figure 1.—Location of Black Mesa Experimental Range on the Western Slope.

transect data were also obtained. A primary purpose was to test one method of estimating plant and ground cover as it relates to runoff and sediment production.

## PHYSICAL CHARACTERISTICS

### Location

The three gaged watersheds that make up part of Black Mesa lie on the Gunnison National Forest, west of the town of Gunnison (latitude 38°N., longitude 107°W.). The 9,800-foot contour wanders through approximately the mid-area of each of the three watersheds. Watersheds 4 and 5 (figs. 2 and 3) drain west into Mesa Creek, and watershed 6 (fig. 4) drains south to Myers Gulch, both tributaries of the Gunnison River.

### Geology, Soils, and Physiography

Paulsen (1969) describes the geology and soils as follows:

> Black Mesa is a segment of the Colorado Plateau at the western extremity of the Elk Mountains. The mesa is capped by a layer of volcanic material, principally Piedra rhyolite and Huerta andesite. The surface is dissected by streams which drop steeply from the rim to the major drainages which bound the mesa: Crystal Creek on the northwest, Curecanti Creek on the southeast, and the Gunnison River on the southwest. The loamy soils are generally fertile and productive, and range in thickness from a few inches to 3 feet or more. They grade into a tighter subsoil and unconsolidated rock. The solum may be more than 8 feet thick. Surface soils are relatively high in infiltration, water-holding capacities, and resistance to erosion.

Physiographic factors were derived from aerial photos and field survey in 1960. The watersheds differ appreciably in area, total stream length, and drainage density (table 1). Also, in 1953 a stock pond was excavated on watershed 5.

Figure 2.—Half the area of watershed 4 is in spruce-fir types.

Figure 3.—

Open herbaceous type predominates on watershed 5.

Figure 4.—

Wind-screened areas extending above the gage site on watershed 6.

Table 1.--Physiographic data for Black Mesa experimental watersheds, Gunnison National Forest

| Watershed | Area | Elevation | Total length of-- | | Drainage density |
|---|---|---|---|---|---|
| | | | Streams | Roads | |
| | *Acres* | *Feet* | *- - Miles - -* | | *Mi/mi²* |
| 4 | 91 | 9,730-9,840 | 1.3 | 0.44 | 9.1 |
| 5 | 169 | 9,770-9,860 | 1.3 | .53 | 4.9 |
| 6 | 272 | 9,620-9,880 | 3.3 | .83 | 7.8 |

### Vegetation

The plant cover is broadly classified as aspen, spruce-fir, and herbaceous (fig. 5). The last, commonly referred to as Thurber fescue grassland, occupies 34 percent of watershed 4, 57 percent of watershed 5, and 47 percent of watershed 6 (table 2). A mixed grass-weed complex occupies the largest area within the herbaceous type. Needlegrasses (*Stipa lettermanii* Vasey and *S. columbiana* Macoun) and Idaho fescue (*Festuca idahoensis* Elmer) are frequently found components. Other sites include: areas dominated by Thurber fescue (*F. thurberi* Vasey), wet and semi-wet meadows with an abundance of grass and forb species, and hummocky areas, termed mima mounds. On some mounds Thurber fescue predominates; on others, hairy goldaster (*Chrysopsis villosa* [Pursh] Nutt. ex DC.) is the major species, or the two intermix.

Table 2.--Distribution of major vegetation types on Black Mesa experimental watersheds, Gunnison National Forest

| Vegetation type | Watershed 4 | | Watershed 5 | | Watershed 6 | |
|---|---|---|---|---|---|---|
| | *Acres* | *Percent* | *Acres* | *Percent* | *Acres* | *Percent* |
| Aspen | 10 | 11.0 | 10 | 5.9 | 91 | 33.4 |
| Spruce | 50 | 54.9 | 16 | 9.5 | 21 | 7.7 |
| Mixed | 0 | 0 | 46 | 27.2 | 32 | 11.8 |
| Grassland | 31 | 34.1 | 97 | 57.4 | 128 | 47.1 |
| Total | 91 | 100.0 | 169 | 100.0 | 272 | 100.0 |

While grassland dominates the cover of watersheds 5 and 6, spruce timber occupies more than half the area of watershed 4. Aspen is the predominant timber type on watershed 6. A mixture of spruce-fir and aspen, termed mixed timber, occupies 27 percent of the area of watershed 5. A timber survey in 1959 found the average age in the aspen type to be 104 years and in the spruce to be 95 years. Basal area per acre determined from that survey averaged 224 $ft^2$ for aspen, 225 $ft^2$ for spruce, and 160 $ft^2$ for the mixed timber type.

## HYDROLOGIC CHARACTERISTICS

### Precipitation

Daily precipitation was recorded from 1920 to 1941 at the Knott Ranch, located approximately 2 miles southeast and 500 ft lower than the experimental area. Mean annual precipitation, measured by water year (October 1 through September 30), at that location was 22.5 inches. Minimum annual precipitation of 13.5 inches occurred in 1931. Maximum precipitation was 29.0 inches in 1929. From 1906 to 1920, records were kept at another location 2 miles further east of the Knott Ranch and about 1,200 ft lower. Annual precipitation averaged 21.8 inches, with maximum and minimum years showing less of a spread than the Knott Ranch record. Sixty-two percent of the annual precipitation fell between October and May.

Two Sacramento 100-inch storage gages with Alter shields were put in operation on the experimental area in the winter of 1958. These were recharged each October, and measured during the spring and at the end of the water year. For the 1958-67 period, precipitation averaged 28 inches. On the average, 71 percent is recorded between October and May. The remainder, termed growing-season precipitation, has ranged from 5 to 14 inches.

In addition to the gages, five snow courses have been run at the same locations each year since 1958. The storage gages and the snow courses (fig. 5) were located to supply precipitation data for the experimental area as a whole.

In 1957, snow courses were run to sample differences among the spruce-fir, aspen, and herbaceous types. The water equivalent on the spruce course was 64 percent, and on the aspen course 90 percent, of the mean for the herbaceous type. Watershed 4 with 55 percent of its area in the spruce type (compared to 10 and 8 percent for watersheds 5 and 6) may accumulate less snow on the average. Snow accumulation on watershed 5 is affected by wind scour in the large, open herbaceous areas. Watershed 6, with the least area in spruce and a long, narrow, protected area probably accumulates the most snow.

Two of the five snow courses encircle the storage gages. The 10-year mean difference between these two snow courses and storage gage catch is not significant at the 5 percent level. Comparable

measurements show that the two methods of sampling precipitation to determine long-term means are equally precise. Encircling snow course and gage precipitation measurements are highly correlated ($r = 0.90$), but the $\pm$ 2-inch standard error of estimate seriously limits using a regression equation for

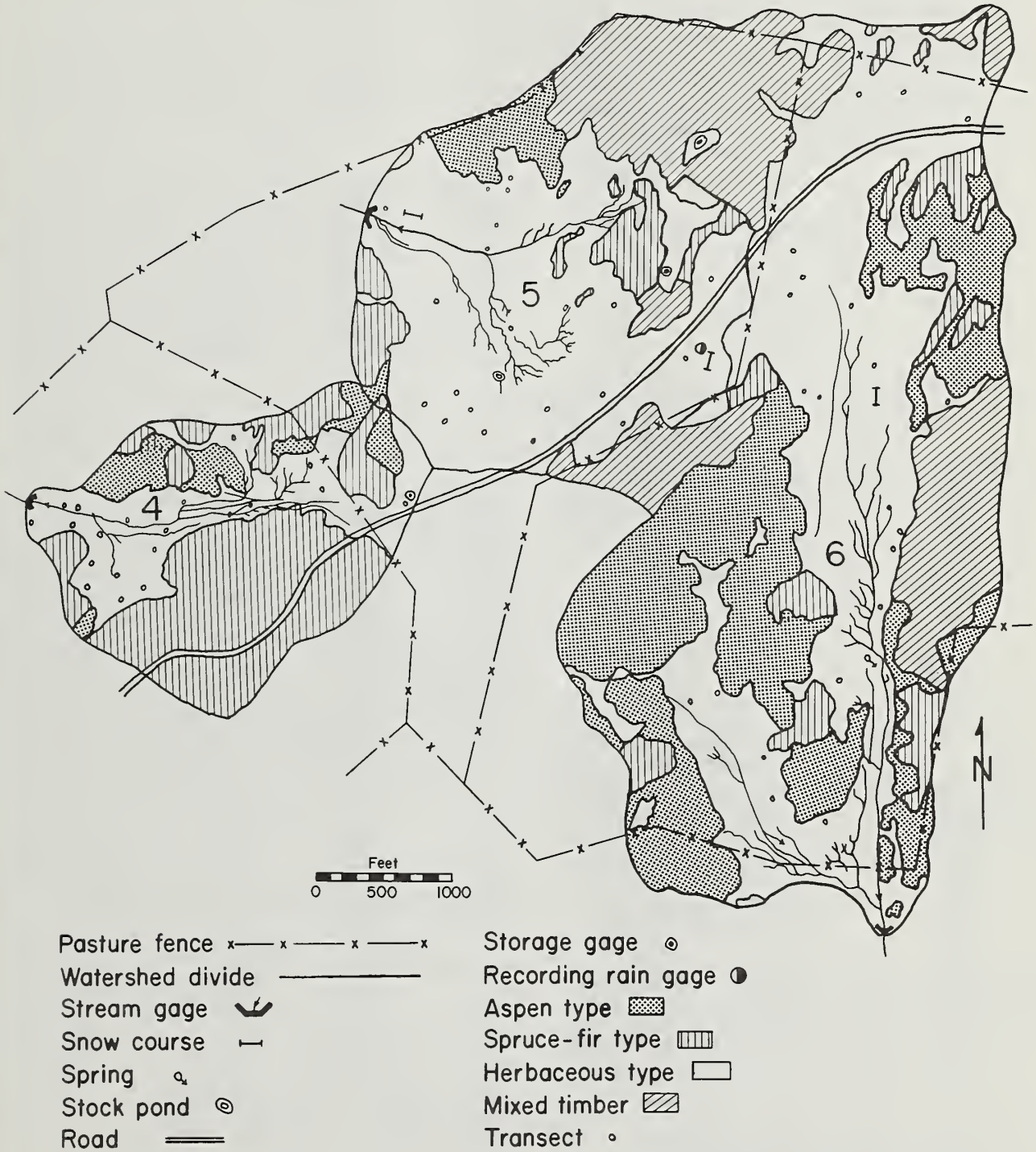


Figure 5.—Black Mesa watersheds.

estimating gage catch from snow course data, as for example, to supply an estimate for 1957 (table 3).

Typically, summer storms are thought of as heavy cloudbursts of high-intensity rain but short duration. The May-October record shows a maximum intensity of 4.56 inches per hour for a 5-minute duration. The greatest amount of rain in a 24-hour period fell in 1959, when a storm dropped 1.10 inches. The

Table 3.--Summary of annual data, Black Mesa experimental watersheds, Gunnison National Forest

| Watershed and year | Precipitation[1] | Runoff | Peak discharge | Suspended sediment | Trapped sediment | Bare intercept[2] |
|---|---|---|---|---|---|---|
| | -- *Inches* -- | | *csm* | -- *lb/acre*[3] -- | | *No. hits* |
| Watershed 4 | | | | | | |
| 1957 | [4] 37.6 | 5.1 | 27 | 136 | -- | 41 |
| 1958 | 34.5 | 4.0 | 21 | 64 | -- | 45 |
| 1959 | 17.2 | .2 | 8 | 54 | 313 | 30 |
| 1960 | 21.1 | 2.2 | 18 | 24 | 128 | -- |
| 1961 | 15.8 | .2 | 8 | 12 | 70 | -- |
| 1962 | 23.0 | .9 | 16 | 154 | 145 | 31 |
| 1963 | 15.5 | .1 | 6 | 3 | 10 | 30 |
| 1964 | 18.5 | 1.2 | 20 | 57 | 124 | 26 |
| 1965 | 23.0 | 1.0 | 15 | 25 | 66 | 24 |
| 1966 | 17.2 | .7 | 13 | 55 | 3 | 17 |
| 1967 | 16.4 | .01 | 2 | 1 | 70 | 18 |
| Mean ± standard deviation | 21.8±7.2 | 1.4±1.6 | 14±7 | 53±48 | 103±88 | 29±9 |
| Watershed 5 | | | | | | |
| 1957 | [4] 37.6 | 8.2 | 36 | 82 | -- | -- |
| 1958 | 34.5 | 5.9 | 37 | 75 | -- | 61 |
| 1959 | 17.2 | 1.4 | 26 | 62 | 134 | 47 |
| 1960 | 21.1 | 5.2 | [5] 96 | 68 | 53 | -- |
| 1961 | 15.8 | 1.2 | 28 | 43 | 26 | -- |
| 1962 | 23.0 | 2.6 | [5] 83 | 56 | 20 | 42 |
| 1963 | 15.5 | .8 | [5] 52 | 71 | 6 | 40 |
| 1964 | 18.6 | 3.3 | [5] 106 | 116 | 28 | 41 |
| 1965 | 24.1 | 3.0 | 28 | 17 | 11 | 39 |
| 1966 | 20.2 | 2.5 | [5] 139 | 103 | 3 | 36 |
| 1967 | 16.4 | .3 | 22 | 11 | 30 | 35 |
| Mean ± standard deviation | 22.2±7.1 | 3.1±2.3 | 59±8 | 64±30 | 34±38 | 43±8 |
| Watershed 6 | | | | | | |
| 1956 | -- | 4.8 | 12 | -- | -- | 40 |
| 1957 | [4] 41.2 | 16.2 | 27 | 99 | -- | -- |
| 1958 | 34.8 | 13.0 | 22 | 84 | -- | 56 |
| 1959 | 19.0 | 3.3 | 10 | 49 | 92 | 36 |
| 1960 | 22.6 | 6.2 | 25 | 218 | 184 | 41 |
| 1961 | 15.9 | 3.3 | 7 | 29 | 40 | 30 |
| 1962 | 25.5 | 7.9 | 15 | 110 | 108 | 38 |
| 1963 | 17.9 | 1.7 | 5 | 10 | 42 | 25 |
| 1964 | 19.5 | 6.2 | 19 | 203 | 190 | 31 |
| 1965 | 26.4 | 8.6 | 18 | 107 | 128 | 34 |
| 1966 | 22.2 | 6.3 | 14 | 83 | 34 | 27 |
| 1967 | 19.1 | 2.0 | 4 | 13 | 12 | 25 |
| Mean ± standard deviation | 24.0±7.4 | 6.8±4.2 | 15±7 | 91±66 | 92±62 | 35±9 |

[1]Storage gage + standard gage no. 1 during runoff period.
[2]Mean of 20 transects/watershed.
[3]Acres in herbaceous type only.
[4]Snow course data + standard gage no. 1.
[5]Peak associated with slush flood.

maximum rainfall intensities for the period 1957-67 are:

| Interval (*minutes*) | Intensity (*inches per hour*) |
|---|---|
| 5 | 4.56 |
| 10 | 3.00 |
| 15 | 2.16 |
| 30 | 1.10 |
| 60 | .68 |
| 120 | .36 |

A much longer record kept at the Knott Ranch from 1920-45 puts the maximum 24-hour precipitation at 1.52 inches. The Knott Ranch record of summer precipitation may be extended back to 1900 (when the gage was at a different location), if a 70 percent reliability is accepted. Fitting the 1900-45 record to Gumbel's extreme value function, gives a 120-year return period for a 24-hour rainfall of 2 inches.

### Runoff and Water Budget

Runoff data were obtained from FW-1 recorders on 90° V-notch weirs for each watershed. Total snowmelt runoff averaged 1.4, 3.1, and 6.8 inches on watersheds 4, 5, and 6, respectively, and 26, 14, and 28 percent of percipitation (table 3).

Some insight into the hydrologic behavior of the watersheds can be provided by calculating their water budgets for the water year 1958, using the soil moisture data reported by Brown and Thompson (1965). Average moisture storage in the upper 8 feet of soil was calculated for each watershed in the fall of 1957 and in the spring and fall of 1958.

The water budgets, in inches, were expressed as $P - RO - ET - DS - = \Delta S$, where:

$P$ = water year precipitation
$RO$ = runoff
$ET$ = evapotranspiration (loss of soil moisture between spring and fall, plus summer precipitation)
$DS$ = deep seepage, calculated as a residual
$\Delta S$ = change in soil moisture storage between fall 1957 and fall 1958

| Watershed | $P$ | - $RO$ | - $ET$ | - $DS$ | = $\Delta S$ |
|---|---|---|---|---|---|
| 4 | 34.5 | 4.0 | 13.9 | 17.8 | -1.2 |
| 5 | 34.5 | 5.9 | 12.9 | 16.3 | -0.6 |
| 6 | 34.8 | 13.0 | 15.4 | 8.1 | -1.7 |

The most striking difference occurs between watershed 6 versus 4 and 5 in deep seepage. Precipitation was similar at the storage gages on the three watersheds, and evapotranspiration varied no more than 2.6 inches. Deep seepage, which varied as much as 9 inches between watersheds with a corresponding difference in runoff, may be attributed to the morphometry (form) of the watersheds. With runoff largely a subsurface phenomenon here, it would be logical to expect the more deeply incised watersheds to have the most runoff, because they would tend to intercept more aquifers. Indicators of the magnitude of incision are (1) the vertical rise along the longitudinal axis of the watershed, and (2) the rise laterally from points within the channel to the divide on either side:

| Watershed | Longitudinal rise (*ft*) | Average lateral rise[2] (*ft*) |
|---|---|---|
| 4 | 110 | 25 |
| 5 | 100 | 35 |
| 6 | 260 | 58 |

It can be seen that watershed 6, which had the greatest amount of runoff, also had the greatest longitudinal and lateral rise.

Yamamoto and Orr (1972) found that maximum basin length was consistently associated with annual water yield. Basin lengths for the three watersheds are:

| Watershed | Maximum basin length (*ft*) |
|---|---|
| 4 | 2,960 |
| 5 | 3,530 |
| 6 | 6,880 |

Again, the watershed with the greatest runoff also had the greatest maximum basin length.

By using average lateral rise ($LR$) and precipitation ($P$) as independent variables, and combining the data from all watersheds, we obtain the following multiple regression for predicting runoff ($RO$):

$$RO = -9.81 + 0.362\,(P) + 0.137\,(LR)$$
$$R^2 = 0.854$$

In summary, it appears that the amount of runoff on Black Mesa is a function of maximum basin length and degree of channel incision, as well as precipitation.

[2] *Average of three cross sections at the lower, middle, and upper portions of the watershed from U.S.G.S. 7½' Ranch Quadrangle.*

Differences in total water yield, however (the sum of runoff plus deep seepage) are minor:

| Watershed | Total water yield (*inches*) |
|---|---|
| 4 | 21.8 |
| 5 | 22.2 |
| 6 | 21.1 |

Instantaneous peak discharge averaged 4 cubic feet per second per square mile (csm) at gage 4, 15 csm at gage 6, and 59 csm at gage 5 (table 3). The higher peaks from watershed 5 are due to the movement of a mass of water and slush down the channel caused by snow-dam failure in the main channel. The high discharges of 50 to 140 csm are due not only to the flood wave, but also to resistance of the water-slush mixture passing through the weir ponds. As many as three slush floods have occurred on successive days.

## Sediment

### Suspended Sediment

A weighted discharge sample was obtained using a DH-48 hand sampler upstream from the stream gage. During spring snowmelt, most samples were taken at 1- to 2-hour intervals between 8 a.m. and 5 p.m. Because sediment weight per sample was obtained by evaporating the sample to dryness, it includes not only the ovendry weight of soil, but also the dissolved solids remaining as a residue. Suspended sediment yields were estimated by averaging instantaneous sediment discharge values and multiplying by the time interval between samples. Total yield was obtained by summing these values for the period of snowmelt runoff. Thus, snowmelt sediment is biased low because (1) sampling is not carried out around the clock, and (2) with stage below the V-notch, sediment discharge is computed as zero. This bias is not thought to be large, however, because it was commonly observed that streams cleared markedly in the hours toward evening, and water levels dropped below the V-notch only on watersheds 4 and 5 during the night. In 1967, sediment samples were taken in the evening and early morning at gage 6. Sediment production amounted to 0.4 to 0.8 lb/acre/day. Duration of runoff has ranged from 2 to 10 weeks, which adds from 28 to 56 lb/acre to the annual totals on watershed 6.

Suspended sediment yields have averaged 53, 64, and 91 lb/acre of herbaceous type on watersheds 4, 5, and 6. Timber acreage was omitted from the per-acre calculation because soil disturbance in the spruce type is negligible. In aspen, the bare intercept from transect data is one-third that in the grassland type, and melt runoff is nearing completion by the time snowmelt in the timber exposes patches of bare soil to overland flow. Average sediment yields based on total area are 18, 37, and 43 lb/acre for watersheds 4, 5, and 6.

The slush floods at watershed 5 transport from 6 percent to 24 percent of the annual suspended sediment yield. After the flood wave passes, the snow close to the channel above and below the gage is covered with sediment (fig. 6). Thus the floods make sediment available to subsequent flow which might otherwise have remained on the watershed, had it not been moved near the main channel.

### Trapped Sediment

Measurement of sediment trapped by the stream gages began in 1959 after the backfill around the weir ponds stabilized. Depth of wet sediment was measured, and bulk density samples were taken each year. Bulk density averaged 0.85 g/cm$^3$ (53 lb/ft$^3$) for all gages averaged for 8 years. Organic matter (as loss upon ignition at 550°C) ranged from 8 to 14 percent for samples taken in 1959 and 1960. Mean trapped sediment for the 1959-67 period amounted to 103, 34, and 92 lb/acre of herbaceous type for watersheds 4, 5, and 6, respectively. Adding these amounts to suspended sediment yields sets total production from watershed 4 at 146 lb/acre/year, 5 at 95 lb/acre/year, and 6 at 184 lb/acre/year.

### Summer-Storm Sediment

During the 11 years of record at Black Mesa, a total of 167 storms occurred, with precipitation

Figure 6.—Sediment after slush flood.

amounting to 0.1 inch or more. The amount of runoff from all storms during the summer averages less than 0.08 inch. Twenty-seven storms which produced runoff have been sampled for sediment. To estimate the sediment yields for the numerous storms which were not sampled, peak discharge for each runoff event was plotted against suspended-sediment yield, and an envelope curve was drawn through the maximum values. This curve was then used to estimate sediment yield for all runoff events in summer. Maximum sediment yield for any one summer was 20 lb/acre of herbaceous type, with a mean yield of 11 lb/acre.

## PLANT AND GROUND-COVER CHARACTERISTICS

Plant and ground cover were measured on 20 permanent 50-ft line transects per watershed to detect changes with time. Observations were made at 6-inch intervals by dropping a ¾-inch loop. Until 1965, transects were run with bare soil, rock, litter, moss, perennial plants (by species), annuals, and overstory shrubs being recorded when encountered within the loop. In 1965, the detailed listing of each species was abandoned in favor of listing bare soil, gopher cast or mound, litter, rock, grass, forb, or shrub. Gopher activity not still identifiable as cast or mound was considered bare soil. After 1965, the transects were run three times per year: first before the cattle were put on pastures; again during late July or August, when the pre-1965 transects were run; and the third in the fall after the current year's crop of gophers had moved out to establish their own burrow systems.

Because the primary thrust of the study was to test for relationships between hydrologic variables and transect data, number of bare soil hits was the "ground-cover" variable chosen for analysis. Aside from infrequent hits on rock, bare soil hits are the complement of ground-cover index. The variable is termed bare intercept because it is only an index of bare soil on the watersheds.

Each of the watersheds is part of a larger pasture (see fig. 5), within which grazing intensity was regulated from 1957 to 1967. Pasture 4 was designated as light intensity, 5 as heavy, and 6 as moderate. The grazing intensity was adjusted to obtain 25, 40, and 60 percent utilization of Idaho fescue (*Festuca idahoensis*). Analysis of year-to-year bare intercept changes reveals a trend with time. On watershed 4, there has been a linear decrease in the total number of bare hits, while on 5 and 6, the decrease fits a power function (fig. 7).

Hits on gopher casts have been most numerous in spring and drop markedly when the same transects are run in fall, corroborating what has been readily observable over the years. During spring runoff, the watersheds appear to have been haphazardly plowed as the gopher casts settle out of the snow tunnels, but by late summer, cattle trampling and rainfall have obliterated most casts. Total number of hits on gopher mounds increases between spring and fall, but the increase is not as marked as the decrease in cast hits. Hits on gopher casts peaked in the spring of 1966, as did mounds in the fall of 1966 on watersheds 4 and 5. On watershed 6, fall of 1967 had the highest total hits on gopher mounds.

## DISCUSSION

### Predicting Streamflow

Correlation analyses using either peak snowpack or storage gage precipitation measurement yield coefficients which are highly significant (table 4). The standard error of estimate for the regression is improved 0.4 inch (about 6 percent of the mean) for watershed 6, with peak snowpack as the independent variable instead of storage gage precipitation. No important changes in regression parameters are evident for the other watersheds.

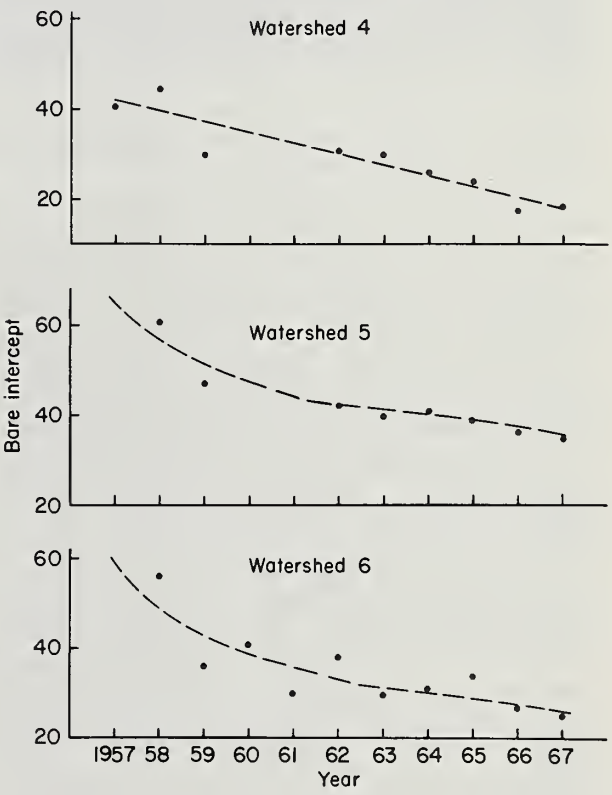


Figure 7.—Bare intercept trend.

Table 4.--Precipitation-runoff analysis by watershed and method of measuring precipitation, Black Mesa experimental watersheds, Gunnison National Forest

| Watershed and measuring method | Correlation coefficient | Standard error of estimate | Regression equation |
|---|---|---|---|
| | | *Inches* | |
| Watershed 4 | | | |
| Gage or | 0.97** | 0.5 | Y = 0.22X - 3.5 |
| Course | | .6 | Y = 0.20X - 3.0 |
| Watershed 5 | | | |
| Gage or | .95** | 1.0 | Y = 0.20X - 3.0 |
| Course | | 1.0 | Y = 0.28X - 3.0 |
| Watershed 6 | | | |
| Gage or | .98** | 1.2 | Y = 0.57X - 6.9 |
| Course | | .8 | Y = 0.55X - 6.1 |

** Significant at 1 percent level.

### Predicting Sediment Yield

The attempt to define a relationship between sediment yield and bare intercept on the total watershed was not successful.

Comparison of bare intercept with suspended sediment yields does not show any large difference between sediment yield in 1958, the year bare intercept was greatest, and other years. Scatter diagrams of sediment versus bare intercept do not indicate any simple relationship which might be tested by correlation analysis.

On the assumption that bare intercept changes could influence the slope of the sediment rating curves due to the streams being able to transport as much load as is delivered to them, covariance analyses were run with the rating curve data for watersheds 4, 5, and 6. The slopes of the rating curves are significantly different for watersheds 5 and 6, while for watershed 4 the slopes are not significantly different at the 5 percent level. If the slopes of the sediment rating curves are plotted for those years that have intercept data available, no trend similar to that found with the transect data is discernible. On watershed 4, comparison of Y-intercept values for the same years as transect data also fails to show any trend. Trapped sediment was highest on watersheds 4 and 5 in 1959, the first year of measurement after allowing 2 years for backfill stabilization. Because transects are measured after spring runoff, the 1958 transect data might logically be related to the 1959 sediment production. This correspondence is the only agreement between bare soil index and sediment production. Subsequent years do not show any further agreement in comparisons within or between watersheds.

### Sediment Sources

Sediment yields from the watersheds are small. If the mean annual suspended sediment loss is spread uniformly over the herbaceous type, this sediment loss can be accounted for by removal of a 0.0001-inch depth per year on each of the watersheds (assuming a sediment density of 2.65 g/cm$^3$). Including trapped sediment adds 0.0002-inch depth per year.

If the significant correlation between sediment discharge and stream discharge is interpreted in classical terms, another place to look for the sediment source is the stream channels. Assuming a wetted perimeter of 1 lineal ft of channel subject to erosion, downcutting of the channels by 0.02, 0.06, and 0.05 inch per year would also account for the mean annual suspended sediment yield of watersheds 4, 5, and 6, respectively. Adding trapped sediment increases the amount removed by 0.06 inch per year on each watershed.

Gopher activity—throwing up new mounds in fall and filling tunnels in the snow with soil during winter—is another source. Where loose soil from mounds or winter casts is in the path of overland flow, the soil is washed out (fig. 8). Probably all suspected sources contribute to the total suspended-sediment load; however, the small loss could be from a few specific areas where soil is readily available to be transported.

## SUMMARY

Average values for the years 1957 to 1967 show better than two-thirds of the water-year precipitation is received between October and May. Ninety-nine percent of total yearly runoff and 89 percent of suspended sediment are measured during spring snowmelt. Summer storms are not severe, with only 5-minute rainfall intensities approaching the design storms of infiltrometer experiments. While suspended-sediment concentration after summer storms can be as much as six times that sampled during snowmelt, total suspended sediment production averages 91 lb/acre from spring runoff and 11 lb/acre from summer storm runoff because of the low storm runoff volume.

Regression analyses of the 11 years of data do not show any relationship between bare soil intercept and water yield or sediment production. Runoff is highly correlated with precipitation on individual watersheds. When data from the three watersheds are pooled for multiple regression analysis, runoff appears to be related to maximum basin length and degree of channel incision as well as precipitation.

Ground cover increased during the study period, even under the heaviest grazing intensity (55 percent

Figure 8.—Washing of gopher casts.

utilization). While the 1959 trapped and total sediment yields on watersheds 4 and 5 were maximums and might be attributed to the maximum bare intercepts recorded in 1958, subsequent years and watershed 6 do not indicate any further correspondence between these variables, either within or between watersheds.

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Eleven years of runoff and suspended sediment data show no relationship to bare soil intercept. This lack of relationship is probably due to the experimental error in measuring these small amounts of sediment. Bare intercept decreased on each watershed during the 1957-67 period even though grazing utilized an average of 40 percent of the grass in the open parks on one of the watersheds.

While suspended-sediment concentration after summer storms can be as much as six times that sampled during snowmelt, total yield averages 91 lb/acre from spring runoff and 11 lb/acre from storm runoff because of the small volume of flow. Based on current erosion classification schemes, these are very minor amounts of "geologic erosion."

**Keywords:** Hydrology, runoff, suspended sediment, Black Mesa watershed.

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